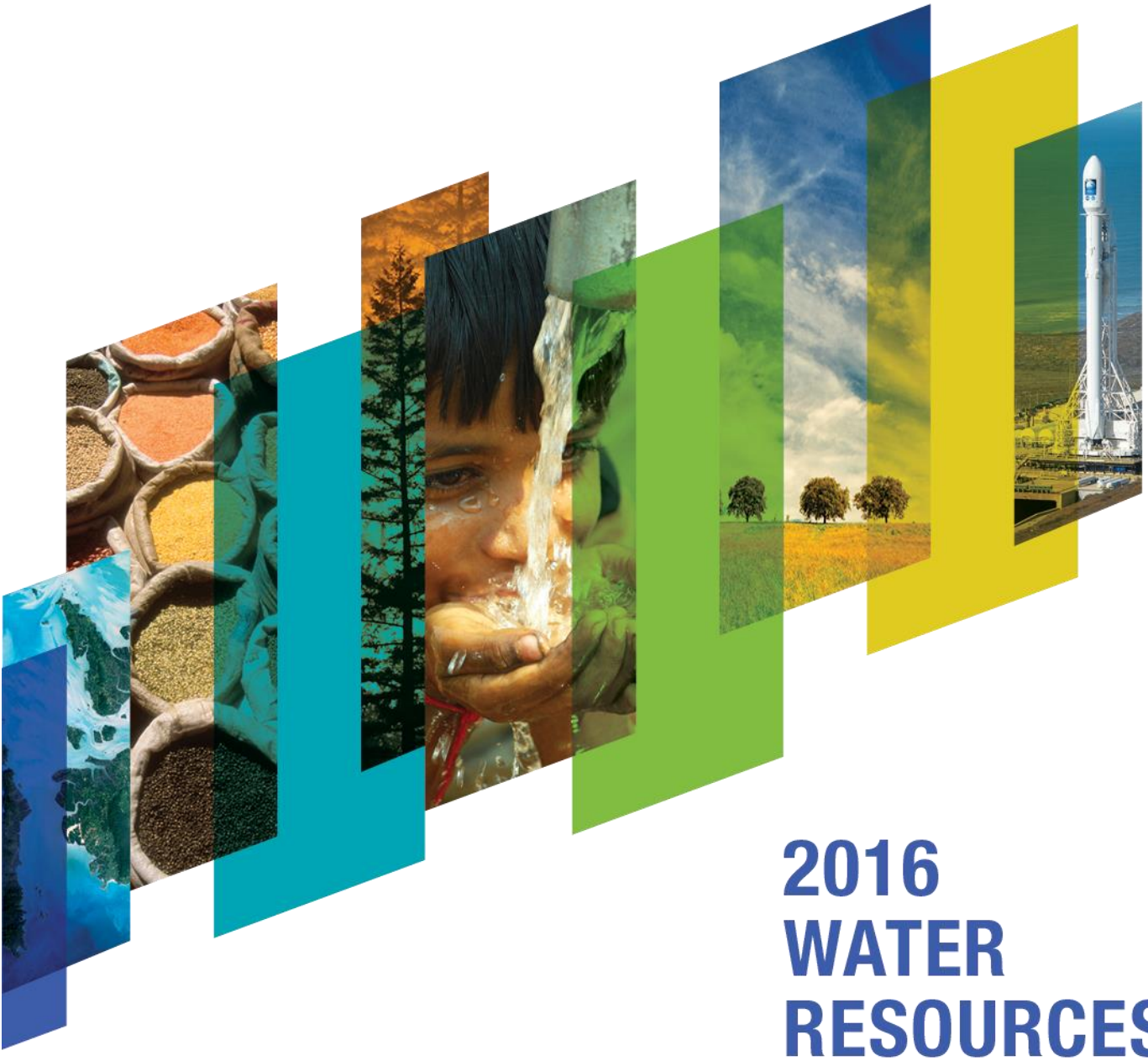
National Aeronautics and Space Administration



2016 WATER RESOURCES

NASA Earth Science
Applied Sciences Program

Water Resources: 2016 Annual Summary

Table of Contents

I. Introduction

The ESD Applied Sciences Program promotes efforts to discover and demonstrate innovative and practical uses of Earth observations. The Program funds applied science research and applications projects to enable near-term uses of Earth observations, formulate new applications, integrate Earth observations and related products in practitioners' decision making, and transfer the applications. The projects are carried out in partnership with public- and private-sector organizations to achieve sustained use and sustained benefits from the Earth observations.

The Applied Sciences Program's applications themes are currently focused on four of the nine Societal Benefit Areas of the interagency Group on Earth Observations: Health (including Air Quality), Disasters, Ecological Forecasting, and Water Resources.[1] The Program includes climate-related influences and impacts within each of these themes and has cross-cutting elements such as Wildfires and Capacity Building.

The Applied Sciences Water Resources Applications area supports the integration of NASA Earth observations and technologies into management tools for the water resources management community. The Water Resources Applications area currently supports a diverse range of projects in its portfolio, addressing topics including drought monitoring and mitigation, snow monitoring and runoff forecasting, water quality, soil moisture, groundwater change, and climatic and ecological impacts on water resources.

NASA's free and open exchange of Earth observations data helps engage and improve integrated observation networks and enables national and multinational regional water cycle research and applications. Satellite and airborne observations and hydrometeorological models can be applied to enhance information from surface observation networks, and they play a critical role in providing information on water resources, especially in data-sparse regions.

NASA satellite and modeling products provide a huge volume of valuable water resources information extending back more than 50 years across a broad range of spatial (local to global) and temporal (hourly to decadal) scales. Many of these products are also available in near real-time (see *https://earthdata.nasa.gov*).

The primary objective of NASA's Water Resources Applications area is to discover, demonstrate, and transfer innovative uses and practical benefits of NASA's Earth science observations, research, and technologies for improved water management to the water resources management community. To accomplish this objective, NASA partners with a diverse group or organizations (e.g. federal agencies, universities, NGOs, and industry) in the United States and internationally to ensure cost-effective and efficacious solutions are provided to water resources managers.

[1] The nine USGEO SBAs are Agriculture, Climate, Disasters, Ecological Forecasting, Energy, Health, Oceans, Water Resources, and Weather.

II. Overview of 2016

The Water Resources Applications Area, team, and community continued to make strides in addressing critical water resources challenges in the U.S. and globally. In addition to supporting a portfolio of 18 ROSES projects spanning topics such as drought, climate impacts on water resources, water quality and streamflow forecasting/flood monitoring, the Water Resources Applications Area kicked-off the Western Water Applications Office (WWAO). WWAO addresses water management issues with an innovative program focused on stakeholder engagement and rapid targeting in Western U.S. water management challenges. The Water Resources Applications Area also was very active in engaging the water resources community in the U.S. (Western States Water Council, National Drought Resiliency Partnership, National Integrated Drought Information System, National Water Quality Monitoring Conference) and internationally (IGARRS, Beijing). In addition, we provided leadership in the establishment of the Group on Earth Observations GLObal Water Sustainability (GEOGLOWS) Initiative for interagency coordination on water security activities, the Committee on Earth Observation Satellites Ad-hoc Working Group, and a USAID Partnerships for Enhanced Engagement in Research (PEER).

III. Assessment

Calendar year 2016 was very productive, including the selection of 8 projects (bringing the total portfolio to 23 for 2017) from the A37 solicitation that was focused on the development of applications with operational partners to address water quality and agriculture water use applications. Furthermore, three impact assessments were initiated to target quantifying the effects of projects on stakeholder decisions.

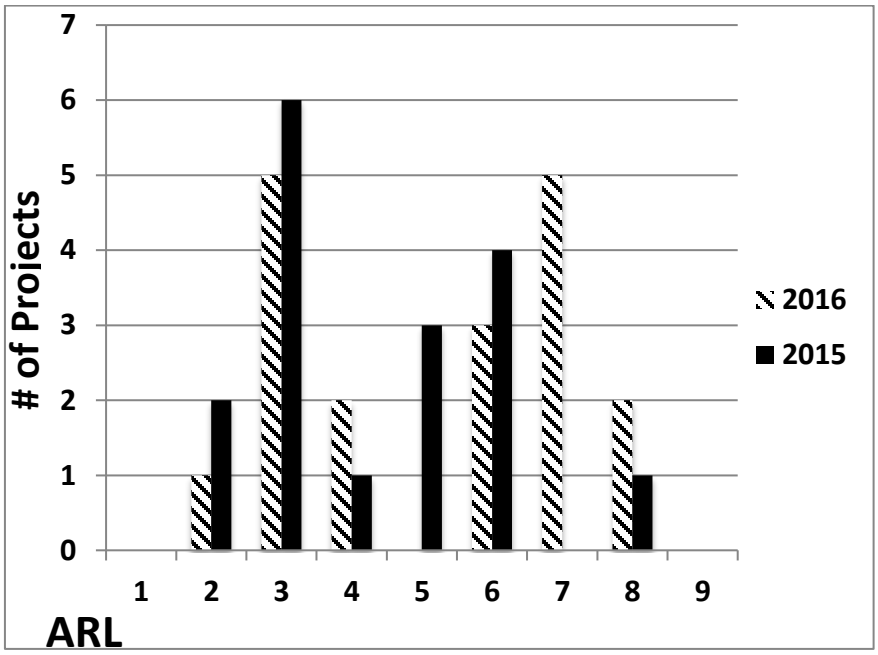
The Water Resources team was highly active in engaging with the operational, policy, and practitioner communities as well as Earth science communities, attending more than 20 meetings and conferences (multiple practitioner meetings such as National Council on Science and the Environment Conference, National Water Quality Monitoring Conference, NOAA National Water Center-PI meeting, USGS-NASA Coordination meeting, U.S. Water Global Water Security Summit, and Water Funders Initiative, among others).

IV. Project Portfolio

The portfolio currently has 25 total projects, which are comprised of seven active projects that were selected from the Feasibility-to-Decisions solicitation in 2011. Nine projects were selected from the A.45 solicitation to develop improved forecasts of water supply anomalies in the mid-term (30-180 day outlooks), and eight projects that were selected from the ROSES 2016 A.37 solicitation on water quality and agriculture water use that will be awarded in 2017. Descriptions of these projects are available in the Appendix.

The table below summarizes the distribution of Application Readiness Levels (ARLs) of the 18 projects that were active during 2016.. During 2016, seven projects advanced one or more ARL.

Water Resources Projects	
ARL	**# of Projects**
9	0
8	2
7	5
6	3
5	0
4	2
3	5
2	1
1	0
Total	**18**



V. Program Management

The Water Resources Applications area kicked-off a new program initiative, the Western Water Application Office at JPL that will target western U.S. water challenges. A new initiative will support Western U.S. water management to put NASA data to work in making decisions by connecting stakeholders with NASA scientists, NASA technology, tools, and data; developing custom solutions through applications projects; and assisting application transition into operational state.

2016 Water Resources Team Meeting

The NASA Water Resources Team Meeting took place in Tuscaloosa, Ala., at the National Oceanic and Atmospheric Administration (NOAA) National Water Center (NWC) on April 26-28, 2016. There were 45 attendees, including currently funded principal investigators (PI) from NASA centers, universities, and other research institutions, as well as colleagues from NOAA

NWC, U.S. Geological Survey, Western States Water Council, World Bank, and the World Wildlife Fund.

On the first day, the agenda was focused on project overviews that were either global or international in geographic scope, with focuses on regions in Africa, South and Central America, and South Asia. Topics included improvement of forecasting water resources anomalies for applications in hydropower generation, groundwater monitoring, and drought monitoring.

In addition to presentations by project PIs and stakeholders, **Brad Doorn** (*NASA Applied Sciences Water Resources Program* Manager at NASA Headquarters) led active discussions about project best practices, how the program can help facilitate new partnerships and engagements, and how it can provide continued support for the PIs and stakeholders in the water resources community. In these discussions, PIs identified several lessons learned from their ongoing work:

- Consistent communication with partner users is essential;
- Flexibility is critical, as scope may evolve over the course of the project;
- Make it easy for partners to provide feedback;
- Partners may need simple summary graphics (tailor the application to their needs);
- Quantifying accuracy increases utility for decision-makers;
- Work closely with stakeholder agencies, understand the "DNA" of their operations; and,
- Let the problem define the solution (and not the other way around)

Other topics of interest included incorporation of training and capacity building, through the NASA Capacity Building program element, Applied Remote SEnsing Training (ARSET; arset.gsfc.nasa.gov), DEVELOP (10-week internship program; develop.larc.nasa.gov), and SERVIR (USAID-NASA project to support international development with Earth observations; servirglobal.net).

On the second day, the meeting included project overviews that focused on water resources challenges in the U.S., including areas such as the Southwest U.S., California, Red River Basin (North Dakota, Minnesota, South Dakota), and Colorado River Basin. Topics spanned drought and flood monitoring, hydrologic models, snow water equivalent, and water quality, among others.

In addition to PI-led presentations, partners from the water resources community also presented, including colleagues from the NOAA NWC, U.S. Geological Survey, and the Western States Water Council. The NOAA NWC also gave the attendees a tour of this recently constructed facility.

Brad Doorn led a second open discussion period, which identified meetings and communities that the Water Resources Applications Area could engage, including the American Water Works Association and the American Society of Civil Engineers.

For additional information, and access to the agenda and presentations, please visit https://c3.nasa.gov/water/resources/14/.

VI. Community Leadership

2016 National Water Quality Monitoring Council, National Monitoring Conference (May 2-6, 2016; Tampa, Fla.)

The NASA Applied Sciences Water Resources team had active participation and conversations at the NWC 2016. We organized 2 oral sessions and supported an ARSET short course that provided an introduction to remote sensing of water quality. The two oral sessions were organized jointly with EPA and USGS, with participation from the USGS Chief Hydrology Scientist as co-moderator. The sessions were well-attended, with about 75 people in each of the sessions. Presentations included topics from remote sensing of oil spills (thickness and extent), harmful algal blooms, colored dissolved organic matter, and methylmercury. There were also presentations that provided an overview of the NASA Applied Sciences program and support for water quality applications. The conference was primarily attended by water resources managers who were interested in water quality at local, state, and federal levels. We had numerous conversations with stakeholders in the water resources community about potential collaborations and opportunities to apply remote sensing to enhance monitoring of water quality.

2016 National Council for Science and Environment – Water-Energy-Food Nexus theme (January 19-21, 2016; Arlington, Va.)

The NASA Applied Sciences Water Resources team partnered with the NASA Capacity Building program and USAID and co-hosted a 90-minute session on "Capacity Building through Applied Research Partnerships for Water-Energy-Food (WEF) Development Challenges." The goal of the symposium was to highlight specific efforts that addressed WEF issues, including SERVIR, PEER, projects funded by the NASA Water Resources Applications area and USAID. The session was well-attended (100+ participants) and was also an excellent opportunity to strengthen interactions between the NASA Applied Sciences Program and USAID, as well as the speakers, which included representatives from the USAID Global Development Lab, Securing Water for Food; the U.S. Water Partnership; SERVIR Applied Sciences Team, and a PI from the Water Resources portfolio. The session also distilled the elements of successful Capacity Building activities, including consistent end user engagement, the importance of ensuring data access and technical exchanges, and being able to leverage resources and synergistic efforts.

2016 Consumptive Use Strategy Workshop: Using Data to Solve the West's Greatest Water Challenges (March 24-25, 2016; NASA Ames Research Center, Mountain View, Calif.)

The Water Resources Team partnered with the Bechtel Foundation, the Water Funders' Initiative (WFI), and Google to jointly organize a workshop focused on advancing the use and availability of remotely sensed data on evapotranspiration and consumptive use. The primary

objective of the workshop was to develop a strategy that outlines how philanthropic organizations, technology companies, research partners, and key decision makers can work together over the next two years to rapidly advance the application of methods to estimate U.S. consumptive water use. This workshop focused on advancing operational use of remote sensing in mapping agricultural water use to improve the management and sustainability of water resources in the Western U.S. The workshop built upon the Google Big Data and the Water Cycle meeting held in July 2015. The workshop was attending by water managers from across the Western U.S., NASA-supported PIs, leading scientists from the Water Resources community, and representatives from technology companies and private foundations. Additional information is available at: http://waterdataworkshop.com/. WFI is a consortium of eight private foundations supported and guided by the S. D. Bechtel, Jr. Foundation, Energy Foundation, William and Flora Hewlett Foundation, Cynthia and George Mitchell Foundation, David and Lucile Packard Foundation, Pisces Foundation, Rockefeller Foundation, Walton Family Foundation, and Water Foundation. WFI is led by Susan Bell, Principal of Susan Bell & Associates and former Vice President of the William and Flora Hewlett Foundation.

2016 Fall Meeting of the American Geophysical Union (December 12-16; San Francisco, Calif.)
The NASA Applied Sciences Water Resources team organized five sessions at the 2016 Fall AGU Meeting on the topic of Remote Sensing Applications for Water Resources Management, Including Irrigation, Droughts, Floods, and Associated Water Cycle Extremes. These sessions attracted 90 abstracts—more than any other single session topic within hydrology-- and the four oral sessions and one poster session were very well attended. The sessions covered both national and international applications of remote sensing for monitoring and management of precipitation, irrigation, drought, flooding, ground water, soil moisture, evapotranspiration, run off, and water quality. These sessions provided an opportunity for the NASA Applied Sciences Water Resources community to interact, share ideas, and foster new collaborations across science teams.

Western States Water Council Irrigation Information Management System Workshop (August 25-26, 2016; San Diego, Calif.)

Members of the Water Resources Team also attended the Western States Water Council Irrigation Information Management System Workshop in San Diego. The Water Resources Team presented an overview of NASA-supported collaborations with the California Department of Water Resources and the California State Water Resources Control Board to integrate satellite data with the California Irrigation Management Information System to support a range of water resources management and irrigation scheduling applications. Participants included water managers from eight western states and the U.S. Bureau of Reclamation. Additional information about the workshop, including the presentations, is available at: http://www.westernstateswater.org/workshop-on-agricultural-weather-station-networks/

VII. Major Accomplishments:

Project: Enhancing the USDA Global Crop Production Decision Support System with NASA Soil Moisture Active Passive (SMAP) Satellite Observations

PI: Dr. John D. Bolten, NASA GSFC

Population growth is an undisputable fact and is driving an increase in food demand and the need for higher global crop production and improved monitoring capabilities. Agriculture faces the challenging task of satisfying increasing food production demands in a sustainable way under conditions of changing climate patterns, more frequent and prolonged weather extremes (e.g. heatwaves, droughts), and declining natural resources. Frequent monitoring of agriculture is key to addressing these challenges. In addition, the ability to quantitatively assess crop yield variability and their capacity for predicting end-of-season corn and soybean yields is an especially pressing need.

Global yield forecasts are the responsibility of IPAD within the USDA Foreign Agricultural Services (FAS) and are generated in part using the Crop Condition Data Retrieval and Evaluation (CADRE) Database Managements System (DBMS). The CADRE-DBMS includes a large number of agrometeorological parameters, including surface and root zone soil moisture, which is a critical parameter for the crop stress and crop alarm models. This project is aiming to significantly improve the performance of the IPAD global yield forecasts by operationally integrating Soil Moisture Active Passive (SMAP)-based soil moisture observations into the USDA FAS CADRE system. The team designed the system using passive soil moisture observations from SMOS mission and ASCAT systems.

In 2016, the team did a thorough study to assess the performance of several operational datasets of vegetation, evapotranspiration, in addition to the satellite-based soil moisture indices being developed for the USDA FAS. The analysis examined a wide array of yield predictor datasets and the used survey-based data from the USDA National Agricultural Statistical Service in a detailed assessment of the water availability timing on the end-of-season crop production during the growing season. In the case study, some of the remotely derived datasets examined (analogous to the SMAP-based product being developed for this project) provide skill comparable to that of in-situ field survey-based data—further demonstrating the utility of these remote sensing-based approaches for estimating crop yield, and showing promising for future applications of SMAP and similar Earth observations for improved global agricultural monitoring.

Project: Development of a Multi-Scale Remote-Sensing Based Framework for Mapping Drought over North America

PI: Dr. Chris Hain, NASA Marshall Space Flight Center

The goal of this project was to develop a drought monitoring tool for North America based on remotely sensed estimates of evapotranspiration (ESI; Evaporative Stress Index). The ESI represents anomalies in the ratio of actual-to-potential ET generated with the thermal remote sensing based Atmosphere-Land Exchange Inverse (ALEXI) surface energy balance model. The LST inputs to ESI have been shown to provide early warning information about the development of vegetation stress with stress-elevated canopy temperatures observed well before a decrease in greenness is detected in remotely sensed vegetation indices. Whereas many drought indicators based on precipitation or atmospheric conditions capture meteorological drought, the ESI is one of few indicators of agricultural drought that reveals actual vegetation stress conditions realized on the ground. As a diagnostic indicator of actual ET, the ESI requires no information regarding antecedent precipitation or soil moisture storage capacity - the current available moisture to vegetation is deduced directly from the remotely sensed LST signal. This signal also inherently accounts for both precipitation and non-precipitation related inputs/sinks to the plant-available soil moisture pool (e.g., irrigation, tile drainage) which can modify crop response to rainfall anomalies. Independence from precipitation data is a benefit for global agricultural monitoring applications due to sparseness in existing ground-based precipitation networks, and time delays in public reporting.

During 2016, this project transitioned to operations within NOAA and achieved an ARL of 9 prior to the completion of the project in December 2016. NOAA implemented the ESI data production system within the NOAA GOES Evapotranspiration and Drought Product System (GET-D), which is currently providing operational 8-km ESI maps for North America. These operational data products have been used by a range of stakeholders and project partners, including the National Drought Mitigation Center, the Texas Water Development Board, the USDA National Agricultural Statistics Service, the USDA Foreign Agricultural Services, the NOAA Environmental Modeling Center, the NOAA Climate Prediction Center, and the G20 GEOGLAM Crop Monitor Initiative.

Supporting the Drought Response in California. While the drought presented numerous challenges to California water managers and residents, it also provided an opportunity to utilize recently developed applications of remote sensing to support monitoring and response to the drought. Over the course of the drought, scientist and engineers worked with California water management agencies to advance the use of a range of remote sensing technologies, and to transition use of these tools from research prototypes to operational applications. During 2016, these remote sensing applications and decision support systems were utilized to improve monitoring of available water supplies stored in dwindling snowpacks, monitor drought impacts on agricultural production and increases in idling of agricultural lands, monitor ground subsidence associated with intensive groundwater pumping, and provide California growers

with information on crop water requirements to support improvements in on-farm water use efficiency during the drought. Together, these applications of remote sensing technologies represent the first time that such a broad array of remote sensing tools have been deployed concurrently in a single region to support drought response. As climate change begins to increase the variability of weather patterns around the world, the California case study provides an example of how an integrated toolset of remote sensing capabilities can be used to support water resource managers in effectively responding to extreme drought events.

Participating in the IEEE International Geoscience and Remote Sensing Symposium (July 10-15, 2016; Beijing, China). The Water Resources Team participated in the 2016 International Geoscience and Remote Sensing Symposium, which provided an opportunity to engage with international stakeholders, Chinese spaceborne remote-sensing programs, and research institutions. The SMAP mission was well represented at the meeting and there were multiple sessions focused on new SMAP-based research and applications. The Water Resources team presented recent advances in SMAP research towards improved water resources management.

Participating in the 2017 Decadal Survey for Earth Science and Applications from Space. The Water Resources Team is represented on the 2017 Decadal Survey Global Hydrology panel, and is also assisting in the planning and reporting of applications within the survey. Strategic planning of future applications of Earth observations is being assessed based on potential societal benefits, scientific discovery, and progress.

Participating in the U.S. Water Partnership All Partners Meeting. The Water Resources Team participated in the U.S. Water Partnership All Partners Meeting, an opportunity to connect with several agencies and NGOs dealing with water security, disaster monitoring and forecasting, and water and big data in the developing world. Topics included transboundary basins and the water security strategy process. Participants included representatives from General Mills, the Water Council, The Stimson Center, and the Global Environment and Technology Foundation.

Participating in the Water and Long-Term Value Conference (October 5-6, 2016, Levi Strauss & Co., San Francisco, Calif.) The Water Resources team participated in this conference and presented an overview of NASA supported applications of remote sensing to enhance the monitoring and management of water resources. The conference was attended by over 150 participants from the commercial sector, including representatives from Nestle, Facebook, Levi Strauss, and Coca-Cola, and provided an important opportunity for the Water Resources Team to engage with the commercial sector and explore new opportunities to apply NASA technologies to support the sustainability of water supplies in the U.S. and around the world.

Supporting the NASA Capacity Building Workshop on Globalizing Societal Application of Scientific Research and Observations from Remote Sensing: The Path Forward. The Water Resources team participated in this workshop, providing input and case examples for use of remote sensing of water resources applications and societal benefit. The team is also contributing to a book chapter that will be one of the outputs from this workshop.

Notable publications for Water Resources Applications Team program activities

The Water Resources Team contributed to three NRC Decadal Survey white papers in response to the first Request for Information – two about Evapotranspiration and one about Coastal and Inland Aquatic Ecosystems.

Notable publications for Water Resources Applications Team program activities

Lee, C.M., Serrat-Capdevila, A., Iqbal, N., Ashraf, M., Zaitchik, B., Bolten, J., Melton, F. and Doorn, B., 2016. Applying Earth Observations to Water Resources Challenges. In Earth Science Satellite Applications (pp. 147-171). Springer International Publishing.

The Water Resources team contributed to *Earth Science Applications Current and Future Prospects,* which was published by Springer Remote Sensing/Photogrammetry. The team led and had co-authorship of Ch. 6, Applying Earth Observations to Water Resources Challenges. The chapter explored internationally focused water resources projects that employed Earth observations to address water resources challenges, with case examples from East Africa (including Tanzania and the Nile), South Asia, and a project with global extent. In reviewing the case studies, the chapter identified several commonalities:

- Partnerships are key to addressing water resource issues, particularly in transboundary water basins
- Capacity building is essential and needs to be an on-going, continuous process
- Earth science observations have immense potential for benefiting users in addressing global to regional scale water challenges

VIII. International Activities

GEO Global Water Sustainability (GEOGLOWS) Update. In 2016 the Water Resources program has supported the development of GEOGLOWS by providing management and secretarial support for the initiative. This support has included the development of the GEOGLOWS initiative proposal document that was accepted by GEO in the summer of 2016 and was the basis of GEOGLOWS inputs for the 2017-2019 GEO work plan. Through decisions at the 2016 annual Integrated Global Water Cycle Observations Community of Practice meeting, a number of GEO community activities including some led by NASA PIs, were incorporated into GEOGLOWS. These included Precipitation (led by George Huffman), Evapotranspiration (led by Forrest Melton), Soil Moisture (now being led by John Bolten) and integrated data products and services (led by Richard Lawford and Bradley Doorn). In the case of precipitation mapping, progress is being made on high resolution precipitation products. NASA is also contributing some activities through DEVELOP and SERVIR to AmeriGEOSS Water and GEOGLOWS. It is anticipated that more GEO Water community activities will join GEOGLOWS in the future as the

international aspects of GEOGLOWS become better recognized. NASA efforts also support other GEO Water activities. For example, drought monitoring through the application of LIS and GRACE are supportive of the GEO Drought initiative and some NASA funded projects in water quality support the GEO Aquawatch Community Activity.

Efforts continue to be made to inform the science community about the latest developments in GEOGLOWS. At the GEO Plenary in Moscow in November 2016, a GEOGLOWS side event, organized by Richard Lawford, informed participants of the progress and opportunities of GEOGLOWS. In December, at the San Francisco AGU meeting, Bradley Doorn chaired a Town Hall meeting on GEOGLOWS. Some new directions for GEOGLOWS have recently emerged including a plan that will actively engage regional programs such as AfriGEOSS and AOGEOSS. In addition, GEOGLOWS is being responsive to proposals such as a recent proposition by the Swiss government to champion the Essential Water Variables in the GEO context. GEOGLOWS is also planning to address appropriate recommendations in the GEOSS Water Strategy. Recognizing that the time has come to mobilize the international GEO community NASA, together with NOAA and the GEO Secretariat, are moving ahead to establish a GEOGLOWS Steering Committee and some Working groups which will move the GEOGLOWS agenda forward in the international forum. In addition, NASA will continue to review its Water Resources program projects to identify those whose deliverables and products that could be recognized as clear contributions to GEOGLOWS.

Leadership with USAID partnerships through PEER. The Water Resources Applications area provided leadership, in conjunction with the NASA Applied Sciences Capacity Building program, to build upon the NASA and USAID partnership through PEER. The solicitation for NASA's first engagement with PEER occurred in October 2014, and resulted in USAID funding 12 international investigators to work with NASA investigators in 2015. Of these 12, three were funded to collaborate with NASA PI partners who are actively funded investigators from the Water Resources portfolio (Dozier, Aghakouchak, and Hossain). In 2016, another 11 PEER proposals were selected to partner with NASA PIs, of which seven were partnered with Water Resources PIs (Melton (two), Bolten (two), Rodell, Jacob, Aghakouchak)

IX. Looking Ahead

The Water Resources Applications area looks ahead to 2017 as a year of growth, expansion, and strengthening of impact analysis across the program—with a plan to implement impact analysis activities and plan for the growth of the Western Water Applications Office (WWAO) and the Global Food Security Office. Projects selected under our ROSES 2016 solicitation will also initiate applied research projects focused on use of Earth observations to address key water sustainability challenges in the areas of water quality and agriculture water use.

The WWAO is a multi-NASA-center effort that is based at the Jet Propulsion Laboratory in Pasadena, Calif. The mission of WWAO is to address western U.S. water resource management concerns through more effective application of NASA assets, capabilities, and expertise.

WWAO's portfolio of activities, thus, includes application development projects—with a hands-on formulation process that crafts efforts to meet specific needs and requirements of project partners (i.e., water resource managers and community); development and implementation of transition projects, including conducting business case studies; and in-depth analyses of user data needs and challenges—through the Needs Assessment and Stakeholder Engagement processes and market studies.

X. Appendix

A. Water Resources Project Highlights from 2016

Project: The Global Reservoir and Lake Monitor (GREALM): Expansion and Enhancement of Water Height Products

Principal investigator: Charon Birkett, University of Maryland

Project year: 3

Year-end ARL: 6

Description: The objective of this project is to provide lake level products in a near real time framework. It will expand the current time line of merged products via integration of historical and future data sets. This includes the historical ESA ERS/ENVISAT dataset, and the NRL dataset. It also includes the future ISRO/SARAL, ESA/Sentinel-3 and NASA/NOAA Jason-3 data sets.

End users: USDA Foreign Agricultural Service (FAS)

Data sources, models, technology: Jason-1, Jason-2/OSTM, TOPEX/Poseidon, Sentinel-3 SARAL GDR

Major accomplishments in CY 2016:

• Extension of the 10- and 35-day products to the end of 2016 year.

• Near real time products based on the SARAL, Jason-3 and Sentinel-3 missions. (Completed for the Jason-3 mission. Archive only SARAL products will released in early 2017)

• The G-REALM system was implemented and refined on a new server cluster in January 2016.

• An additional 190 lakes and reservoirs were added to G-REALM during April-August 2016.

• G-REALM became operational with Jason-3 data in December 2016.

* * *

Project: Assessing Water Resources in Remote, Sparsely Gauged, Snow-Dominated Mountain Basins

Principal investigator: Jeff Dozier, University of California, Santa Barbara

Project year: 3

Year-end ARL: 6

Description: Utilizing MODIS data and GDAS/GLDAS assimilations, this project estimated seasonal snow volumes, relative to historical trends and extremes, in snow-dominated mountains that have emerging or enduring insecurity related to water resources, to support government operations and analysis for aid organizations. It aimed to identify, on regional and local bases, "crisis" and near-crisis events compared against historical data.

End users: U.S. Army Staff, U.S. Army Corps of Engineers, U.S. Embassy (Islamabad and Kabul), California Department of Water Resources (CDWR)

Data sources, models, technology: MODIS (VIIRS in future), SSM/I assimilations from GDAS and GLDAS. Own models and from NOHRSC.

Major accomplishments in CY 2016:
- Completed reconstruction of time-series of snow water equivalent for the 8 basins in Afghanistan;
- Demonstrated that retrievals of SWE from passive microwave have close correspondence to reconstructed SWE during drought conditions;
- Project continuing to collaborate with USACE CRREL and USAF 14th Weather Squadron to review results and develop transition strategy.

* * *

Project: Development of a Multi-Scale Remote Sensing-Based Framework for Mapping Drought over North America

Principal investigator: Christopher Hain, University of Maryland

Project year: 3

Year-end ARL: 9 (Final)

Description: The project has developed a multi-scale drought monitoring tool for North America based on remotely sensed estimates of evapotranspiration (ET) derived from thermal infrared retrievals of land surface temperature (LST): the Evaporative Stress Index (ESI). The expanded ESI domain was evaluated with respect to drought metrics used in the United States Drought Monitor (USDM) and the North America Drought Monitor (NADM), along with commonly used drought indictors.

End users: National Drought Mitigation Center, U.S. Drought Monitor, the Texas Water Development Board, the USDA National Agricultural Statistics Service, the USDA Foreign Agricultural Services, the NOAA Environmental Modeling Center, the NOAA Climate Prediction Center, and the G20 GEOGLAM Crop Monitor Initiative

Data sources, models, technology: ALEXI ESI, MODIS LAI

Major accomplishments in CY 2016:

- During 2016, this project fully transitioned to operations within NOAA and achieved an ARL of 9 prior to the completion of the project in December 2016. NOAA implemented the ESI data production system within the NOAA GOES Evapotranspiration and Drought Product System (GET-D), which is currently providing operational 8-km ESI maps for North America. These operational data products have been used by a range of stakeholders and project partners, including the National Drought Mitigation Center, the Texas Water Development Board, the USDA National Agricultural Statistics Service, the USDA Foreign Agricultural Services, the NOAA Environmental Modeling Center, the NOAA Climate Prediction Center, and the G20 GEOGLAM Crop Monitor Initiative.

* * *

Project: Global Monitoring of Agricultural Drought: A Contribution to GEOGLAM

Principal investigator: Inbal Becker-Reshef, University of Maryland

Project year: 3

Year-end ARL: 7

Description: The objective is to coordinate international efforts to prototype the GEOGLAM crop outlooks for the G-20 AMIS Initiative. These are transparent, timely, qualitative crop condition assessments in primary agricultural production areas which reflect an international consensus.

End users: GEO-GLAM Global Agricultural Monitoring Community of Practice; G20 Agricultural Market Information System; USDA

Data sources, models, technology: MODIS Vegetation Indices, anomaly-based indicators, Temperature, Precipitation, Agricultural Statistics, crop calendars, cropland masks, Expert knowledge, GIS web systems

Major accomplishments in CY 2016:

- As a part of the CM4AMIS activity, the project team has worked closely with international partners to develop a set of "best-available" crop calendars and crop type masks based on partner inputs, further exemplifying the synergy possible through multi-agency collaboration
- Established an operational relationship with the G20-AMIS initiative and international colleagues to produce a monthly global agricultural assessment
- Provide operational monthly reports on crop conditions published within the AMIS Market Monitor
- Designed and implemented a web interface for global partners to provide agricultural crop outlooks every month
- Initiated dialogue with international partners for development of country specific crop monitoring and stress GLAM system and initiated prototype development
- Secured US partnerships with USDA leadership
- Secured international partnerships with over 30 agencies and organizations
- Developed categories of crop conditions
- Developed customized products (maps and charts) that are understandable for policy makers and economist communities
- Developing global crop calendars and crop specific crop masks for the AMIS countries with the help of international partners
- Received recognition for our work-ESRI Special Achievement in GIS Award
- Developed prototype Rangelands Monitor interface
- Started integration between the Crop Monitor and the GLAM interfaces
- Started integration between the Crop Monitor and Early Warning Crop Monitor
- Presented at multiple meetings & conferences including AAG, AGU, ESRI, IMAAFS, AMIS, and ComsNet

* * *

Project: Mitigation of Drought Impacts on Agriculture through Satellite Irrigation Monitoring and Management Support

Principal investigator: Forrest Melton, NASA ARC and California State University, Monterey Bay

Project year: 3

Year-end ARL: 7

Description: The Satellite Irrigation Management Support (SIMS) project is a NASA-supported effort to apply publicly available data from Earth-observing satellites to map crop cover, crop coefficients, and crop evapotranspiration. The goal of the project is to develop information products and tools from satellite data to provide decision support for water managers and agricultural producers for agricultural water management and irrigation scheduling.

End users: California Department of Water Resources (CDWR), Western Growers Association, University of California Cooperative Extension, USDA Agricultural Research Service, Tanimura & Antle, Farming D Ranch, Pereira Bros. & Sons, Booth Ranches, Fresh Express, Ryan Palms Farms, Del Monte, Inc.; Constellation Wines, E. & J. Gallo, Dole, Inc., Driscoll's Farms, Meyer Farms, Huntington Farms, D'Arrigo Bros.

Data sources, models, technology: TOPS, MODIS, Landsat, Sentinel-2

Major accomplishments in CY2016:

- An application programming interface (API) was completed for SIMS and integration with the University of California Cooperative Extension (UCCE) CropManage irrigation decision support tool was completed. CropManage currently serves hundreds of growers in California and provides irrigation management support across thousands of acres. Data from SIMS is now available to growers and irrigators through CropManage.
- The SIMS web interface was publicly available during 2016. Reports were generated on a weekly basis for partner growers, with combined management of more than 100,000 acres.
- Requirements and use cases for transition of SIMS to CDWR were developed. Work is currently ongoing with CDWR to transition SIMS to CDWR for sustained operations.
- Four years of validation studies completed in collaboration with CDWR. Results currently being compiled and prepared for publication.
- Four years of field studies have been conducted for vegetable crops in collaboration with USDA and UCCE to quantify the potential for reductions in applied water and associated changes in crop yields. Studies conducted to date demonstrate potential for reductions in applied water of 20-40 percent, without any statistically significant changes in yield.
- Ongoing work with CDWR to develop strategy to quantify statewide benefits of using ET-based irrigation management strategies.

* * *

Project: Integration of Precision NASA Snow Products with the Operations of the Colorado Basin River Forecast Center to Improve Decision Making

Principal investigator: Thomas Painter, NASA Jet Propulsion Laboratory

Project year: 2

Year-end ARL: 7

Description: The project developed and delivered MODIS data products, which the Colorado Basin River Forecast Center (CBRFC) began integrating into its operations in 2013. CBRFC, which is run by the National Weather Service, generates daily and seasonal streamflow forecasts for the Colorado River Basin and eastern Great Basin.

End users: water managers, reservoir managers, government officials

Data sources, models, technology: MODSCAG, MODDRFS

Major accomplishments in CY 2016:

- Ongoing use and refinement of use of near real-time MODSCAG by CBRFC.
- Ongoing use of near real-time canopy-adjusted MODSCAG fractional snow covered area into CBRFC operations.
- Continuing use of near real-time MODDRFS dust radiative forcing to update snowmelt rates in CBRFC operations.
- Quantification of CBRFC SNOW-17 forecasting errors across Colorado River Basin relative to dust radiative forcing anomalies from near real-time MODDRFS.
- Modeling of runoff at forecast points with VIC and MODSCAG.
- Project was highlighted in a Phys.org article which described the project impacts and benefits to the CBRFC: https://phys.org/news/2017-01-nasa-colorado-river-basin.html

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Project: Fallowed Area Mapping for Drought Impact Reporting and Decision Making

Principal investigator: James Verdin, U.S. Geological Survey

Project year: 3

Year-end ARL: 7

Description: Using MODIS and Landsat data, the project has demonstrated the feasibility of a remote sensing fallowed land monitoring service. This is a joint effort by USGS EROS, USDA NASS, CDWR, and NASA Ames Research Center to improve the timeliness of fallowed area information products to support within-season decision making on drought disaster declarations and proposed water transfers, and gauge impacts on local economies and employment.

End users: CDWR, U.S. Bureau of Reclamation, California Farm Water Coalition, Western Growers Association, National Integrated Drought Information System

Data sources, models, technology: Expedited and specialized processing of MODIS 250m data, Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI

Major accomplishments in CY 2016:

- Successfully sustained capability for within season mapping of idle acreage (advanced delivery of information >10 months).
- Monthly estimates generated by the project team for March – September 2016 and delivered to DWR within two weeks of end of month.
- Overall accuracy has been approx. +/- 15 percent or better in all months, exceeding CDWR specified targets for accuracy.
- Good agreement between USDA/NASA year-to-date idle estimates.
- Data presented to Governor's Drought Task Force by CDWR.
- Data used as input to decision making for allocation of emergency drought relief funds to food banks and social service agencies in impacted counties.
- Transition plan requirements and use cases developed in collaboration with CDWR. Transition of implementation for California ongoing for sustained operation by CDWR.
- Expansion of project capabilities to Washington and Nevada initiated with matching support from the Western Water Applications Office and the National Integrated Drought Information System.

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Project: The Quick Drought Response Index (QuickDRI): An Integrated Approach for Rapid Responses Agricultural Drought

Principal investigator: Brian Wardlow, University of Nebraska at Lincoln

Project year: 3

Year-end ARL: 7

Description: The project is investigating the development of a rapid-response drought monitoring tool prototype called the Quick Drought Response Index (QuickDRI) that integrates satellite-based vegetation, evapotranspiration, and soil moisture data with climate index and biophysical data. QuickDRI will be designed to map and monitor early-stage and rapid-onset vegetation flash drought stress, which is critical information needed to enhance the targeted application of the U.S. Drought Monitor (USDM) and associated key decision-making activities such as the multimillion-dollar USDA Livestock Forage Disaster Program that use the USDM.

End users: USDA Farm Service Agency, Livestock Forage Disaster Program, NOAA National Weather Service

Data sources, models, technology: Multiple NASA Earth science products characterizing key components of the hydrologic cycles affecting vegetation drought stress will be integrated into QuickDRI, including MODIS vegetation index data, GRACE and NLDAS soil moisture anomalies, and a *GOES*-based Evaporative Stress Index (ESI). Models will subsequently be applied to gridded data to generate maps of short-term vegetation stress patterns across the continental United States.

Major accomplishments in CY 2016:

- Operational QuickDRI processing system was tested during the 2016 growing season to produce near real-time QuickDRI maps for the CONUS.
- USDM authors were sent operational QuickDRI maps during the summer and fall 2016 for evaluation. General feedback was collected regarding the general ability of QuickDRI to characterize short-term changes in drought conditions that were occurring during that time period across the CONUS.
- The NASA/GSFC team implemented new GRACE data assimilation approach that makes use of the 1-degree GRACE terrestrial water storage anomaly grids directly rather than averaging over river basins first. This should improve the accuracy of the assimilated output making it more applicable to QuickDRI and drought monitoring applications.
- Historical data base of QuickDRI inputs over the CONUS has been updated to included data spanning through 2016.
- Plans are underway to engage the broader USDM expert/stakeholder network across the CONUS for the 2017 growing season to acquire feedback on their accuracy and usefulness for the USDM and the development of informational products.
- Planning continued on the QuickDRI website to disseminate near real-time, beta information products from the operational QuickDRI system as USGS EROS to the USDM authors and their expert network. Work on the website is scheduled to begin in early 2017 and a beta-version of the site available for review and testing by early spring.

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Project: Predicting Middle Eastern and African Season Water Deficits using NASA Data and Models

Principal investigator: Christa D. Peters-Lidard, Goddard Space Flight Center

Project year: 2

Year-end ARL: 3

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objective of this work is to develop a season water deficit forecasting system that is relevant for USAID and U.S. Army Corps of Engineers in the Middle East and Africa. These activities will be based on existing/mature NASA and NOAA Earth science capabilities. The primary work has two goals: (1) align and improve the USAID's Famine Early Warning Systems Network (FEWS NET) and (2) describe water supply and water supply anomalies in the region of interest through a suite of indicators.

End users: managers at the U.S. Agency for International Development, U.S. Army Corps of Engineers, and International Center for Biosaline Agriculture

Data sources, models, technology: GEOS-5, CFS seasonal forecasts, LIS, AMSR-E, ASCAT, SMOS, SMAP, GRACE, LDAS, DSSAT

Major accomplishments in CY 2016:

- Made improvements to the Noah-MP land surface model after finding the model had run-time errors, including division by zero and round-off errors.
- Implemented forecast capabilities in to LIS, including ensemble streamflow prediction (ESP), climatology-based and downscaled seasonal climate forecast capability.
- HYMAP routing and stream flow model now supports ensemble simulations for supporting the ensemble water availability and streamflow forecasting work.
- The key LSMs, Noah-MP, Catchment, Noah 3.3 and VIC, have all been run for 35-year historic simulations for East Africa, compared and being evaluated. Full water and energy budget analysis and streamflow evaluations have been performed. Comparing results with NLDAS validation and benchmarking efforts over North America, where more validation datasets reside.
- The LIS DA system has been updated to include the support for computing assimilation innovations in the observation space. This capability allows the optimal use of the remote sensing information at the same spatial scale of the measurement. The added errors from spatial upscaling/downscaling are minimized.
- The CLSM and Noah-MP models have been updated to include the support for soil moisture data assimilation for a variety of satellite sensors such as ASCAT and SMOS. The support for SMAP is ongoing.

- The support for gridded GRACE TWS measurements for assimilation within CLSM has been developed (Paper reference: Kumar et al., 2016).
- Set up the LIS framework (LDT, LIS, LVT) for the Blue Nile River region to use as our main testing domain for implementing and demonstrating the full end-to-end forecasting system prototype and more complete analysis for the major components outlined for this project. Starting with the Catchment LSM model for initial testing, then including Noah-MP in start of 2017 to benchmark and test its components.
- Tested and evaluated three forecasting methods so far: 1) climatological forecasts; 2) Ensemble Streamflow Prediction (ESP); and, 3) original (uncorrected) GEOS-5 seasonal forecasts; compared with CLSM open-loop (OL) runs forced with Open-loop (OL) runs forced with MERRA2 + CHIRPS2.
- Completed the bias-correction and downscaling of the GEOS5 forecasts.

Project: Towards Operational Water Resources Management in South Asia Exploiting Satellite Geodetic and Remote Sensing Technologies

Principal investigator: Faisal Hossain, University of Washington

Project year: 2 year

Year-end ARL: 6.5 (Average between ARL9, ARL7, ARL3)

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objectives of this project are to develop and transition multiple tools to respective end users. These tools include: (1) Satellite Precipitation and GCM-based forecasting of anomalies of water availability using hydrologic model for Ganges-Brahmaputra and Indus basins for IRSA and IWM-WRP; (2) GRACE and Altimetry (JASON-2/3, AltiKa, Cryosat-2, Sentinel-3, ICESat-2), ERA-Interim/MODIS based monitoring of glacier mass balance, elevation change for selected glacier and snow extent/depth change; (3) Satellite Altimetry based monthly-to-3-monthly monitoring of storage anomalies of surface water artificial reservoirs for IRSA; (4) GRACE-based monthly to seasonal monitoring of groundwater storage anomalies with sub-monthly frequency of updating for PCRWR and IWM-WRP; and, (5) Satellite Altimetry-based river level forecasting in the Ganges, Brahmaputra and Indus basins in near real-time made available at a web portal.

End users: Department of Hydrology and Meteorology (DHM-Nepal), Department of Hydromet Services (DHMS-Bhutan), Pakistan Council for Research on Water Resources (PCR WR-Pakistan), Indus River System Authority (IRSA-Pakistan), Institute of Water Modeling-Water Resources and Planning (IWM-WRP-Bangladesh), Flood Forecasting and Warning Center (FFWC-Bangladesh)

Data sources, models, technology: GRACE, JASON-2/3, AltiKa, Cryosat-2, Sentinel-3, MODIS, GCMs

Major accomplishments in CY 2016:

- GRACE data now being operationally produced and used by PCRWR for monthly groundwater storage change for Indus Basin
- VIC-based surface water nowcast and hindcast now available for South Asian stakeholders
- Satellite-based SMS system for improving water conservation for Pakistan farmer launched on a pilot scale in April 2016, using GPM precipitation and Potential Evapotranspiration (700 farmers receiving information)
- GRACE data for monitoring snow/glaciers is in process of being operationalized (working on web-portal currently)

Plans or expectations for 2017:

- Continued strong engagement with all end user agencies
- Fully operationalize use of GRACE data for snow/glacier monitoring via a web portal
- Increase satellite-based SMS system for monitoring farm conditions from 700 to 14000 farmers
- Integrate seasonal forecast component to surface water nowcast/hindcast tool

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Project: Enhancing the USDA Global Crop Production Decision Support System with NASA Soil Moisture Active Passive (SMAP) Satellite Observations

Principal investigator: John Bolten, NASA Goddard Space Flight Center

Project year: 2

Year-end ARL: 4

Description: The primary goal of this project is to provide NASA products, tools, and information to the USDA Foreign Agricultural Service to advance agricultural productivity forecasting ability of the CADRE crop forecasting system.

End users: USDA FAS

Data sources, models, technology: SMAP, ASCAT, GPM, SMOS

Major accomplishments in CY 2016:

- Publication on system assessment and potential yield forecasting was accepted in Journal of Selected Topics in Applied Earth Observations and Remote Sensing
- System transition from USDA FAS to NASA GSFC GLAM system was tested and planned
- Received very positive feedback from both USDA FAS and USDA WAOB concerning the relative accuracy of the product (versus existing root-zone soil moisture data products).

- Completed detailed assessment of new observation error and bias correction for the operational data assimilation system
- Hired support scientist to lead the transition of operational soil moisture system from USDA ARS to NASA GSFC (Nazmus Sazib)
- Produced GPM-Soil moisture animation for Hyperwall presentations (http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4443)
- Presented results at several domestic and international conferences (e.g., AGU, EGU).
- Several project highlights were featured at NASA GSFC and the PI discussed SMAP and SMAP-based data systems on Maryland Public Television and BBC documentary.

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Project: Decision Support System to Enhance Water Quality Modeling and Monitoring using Remote Sensing Data

Principal investigator: Ben Stanford, Hazen and Sawyer

Project year: 2

Year-end ARL: 3/4

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The goal of this project is to develop a decision support system for partners that utilizes remote sensing information to predict anomalies in source water quality, looking at parameters such as haloacetic acids, nutrients, and organic matter.

End users: New York Department of Environmental Protection, Colorado Water Conservancy District, and City of Raleigh, NC

Data sources, models, technology: SMAP, GPM, ASTER, MODIS, Giovanni, TRMM, TMPA, NLDAS-VIC

Major accomplishments in CY 2016:
- Held two in-person and remote meetings with staff and management from Northern Water to better understand their system and analytical needs
- Identified additional partner utilities for future testing phases of the project
- Refined data dashboard for visualizing remote sensing and in suit data, including time series, scatter plots, and correlations statistics viewing
- Developed scripts to estimate likelihood of in situ water quality parameter exceedance threshold based on value of remote sensing parameters during prior seasons

Plans or expectations for 2017:

- Continued investigation into modifying scripts for logistic regression to apply remote sensing data
- Continued DSS user requirement refinement to support software development

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Project: Integrating GRACE and GRACE Follow-On Data into Flood and Drought Forecasts for the Continental U.S.

Principal investigator: Matt Rodell, NASA GSFC

Project year: 2

Year-end ARL: 4

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objective of the project is to build upon a current suite of soil moisture and groundwater wetness indicators employed by the project team and end users to develop 30-90 day, 0.125° gridded predictions of water storage conditions and runoff for the continental U.S. using GRACE and GRACE-FO and to test them as inputs to existing drought, river flow, and flood decision support systems at the NDMC, NWS/NCRFC, and USACE.

End users: National Drought Mitigation Center

Data sources, models, technology: GRACE, GRACE-FO, Catchment Land Surface Model, GEOS-5

- Near real time soil moisture and groundwater wetness indicators based on GRACE data assimilation within the Catchment land surface model have been produced weekly and distributed through the NDMC data portal since 2011.
  They have been tested by USDM authors and used by them as a resource since 2012.
  Historical (2002-15) GRACE DA based groundwater and SWE data for the Red River of the North basin are now being evaluated by NOAA NCRFC.
- NASA/GSFC has refined the model and DA parameters within LIS.
- NASA/GSFC increased the spatial resolution of its operational GRACE DA simulations and resulting wetness indicators to 0.125°.
- NDMC is now distributing the new 0.125° wetness indicators from its website and has replaced the old 0.25° archive.
- NDMC is designing a new GRACE DA wetness indicator product distribution webpage.
- JHU has completed objective regionalization of the CONUS and is now downscaling seasonal forecasts for forcing the model into the future.
- U. Texas delivered regularized GRACE hydrology fields that are now being used as input to the GRACE data assimilation runs.

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Project: Satellite Enhanced Snowmelt Flood Predictions in the Red River of the North Basin

Principal investigator: Jennifer Jacobs, University of New Hampshire

Project year: 2

Year-end ARL: 3

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objective of the project is to improve the NCRFC's operational flood prediction in the Red River Basin by using NASA products to update the NWS's operational forecasting models (SNOW17 model and Sacramento Sac-SMA) with spatially distributed estimates of state variables, including snow water equivalent, snow melt phase, snow-covered area, and meltwater partitioning parameters based on antecedent soil moisture. Once proven on the RRB, the same techniques will be available for use elsewhere within the NCRFC area of responsibility and at the remaining 12 RFCs.

End users: North Central River Forecast Center

Data sources, models, technology: SMM/I, AMSR-E, AMSR2, SMOS, SMAP, MODIS, SNODAS,

Major accomplishments in CY 2016:

- Developed strategy to compare snow observations from traditional airborne gamma, USACE snow surveys, and ground sites to satellite observations
- Results indicate reasonable agreement between passive satellite and airborne gamma observations, but further processing needed for end users
- Results from comparison of satellite soil moisture observations to in situ measurements indicate good agreement
- Good continuity determined between AMSR-E and AMSR2 SWE estimates
- A visit by NCRFC forecaster Brian Connelly to UNH in Nov. 2015 allowed further discussion and documentation of the NCRFC forecasting process
- Demonstrated viability of microwave snow and soil moisture products in Red River of the North Basin
  Moving forward on testing model performance incorporating satellite data
- Updated version of NCRFC CHPS river forecasting model standalone installed at UNH
- Model run using historical forcing through water year 2013, and model states & parameters exported for Buffalo River forecast basins
- Compared output from historical model runs of CHPS to USGS stream gauge observations for identification of parameters that need recalibration

- Satellite snow water equivalent (SWE) maps and times series (including satellite and in situ measurements) created on a weekly basis January-March 2016 and distributed to NCRFC for use during forecasting
- Satellite soil moisture maps and times series created on a weekly basis during summer & fall 2016 and shared with NCRFC

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Project: Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts

Principal investigator: Mekonnen Gebremichael, UCLA

Project year: 2

Year-end ARL: 3

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. This project aims to improve reservoir operations for hydropower production for multiple utilities in East Africa by utilizing remote sensing data and seasonal climate forecasts in respective Decision Support Systems.

End users: Ethiopian Electric Power Corporation, Tanzania Electric Company

Data sources, models, technology: TMPA, CMORPH, emerging GPM, ASCAT, AMSR2, SMOS, MODIS, Landsat, JASON, ENVISAT, MIKE BASIN, MERRA, CFS, NMME

Major accomplishments in CY 2016

- Developed seasonal forecast bias and calibration algorithms
- Enhanced seasonal forecasting skill of numerical weather prediction, statistical approaches explored via large scale geophysical connections to catchment rainfall – ongoing development
- Sub-seasonal to seasonal (2-week to 2-month lead-times) forecasts archived for further analysis
- Developed two different visualization resolutions for East Africa displays
- Tested and identified which methods are most relevant and appropriate for end user hydropower reservoirs
- Developed process for reliably generating climate forecasts at various scales for East Africa

Plans or expectations for 2017:

- Continued stakeholder engagement, including planning and hosting a user workshop with lead of East Africa Power Pool

- Collaborating with FAME project to compare results / share datasets (such as gauge information) over East Africa domain (sub-seasonal forecasts/discharge data), sharing downscaling and bias correction methodologies
- Continued tailoring of climate forecasts to hydrologic applications and reservoir optimization

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Project: Advancing Drought Onset Detection and Seasonal Prediction Using a Composite of NASA Model and Satellite Data

Principal investigator: Amir AghaKouchak, University of California, Irvine

Project year: 2

Year-end ARL: 4

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The overarching goal is to improve drought monitoring and prediction in California through: (a) Using NASA's Atmospheric Infrared Sounder (AIRS) relative humidity and water vapor to improve drought early onset detection and prediction; (b) developing a multivariate modeling framework for composite drought assessment; and, (c) developing a framework for quantitative and probabilistic assessment of drought by integrating satellite data into an analog-based drought prediction model. The project will be conducted with investigators from the California Department of Water Resources (CDWR).

End users: CDWR

Data sources, models, technology: NASA Atmospheric Infrared Sounder

Major accomplishments in CY 2016:
- The team presented results to date from the multivariate modeling framework at a workshop organized by CDWR collaborators (Jeanine Jones and Mike Anderson) in June 2016.
- The project team shared the source codes of the recently developed hybrid statistical-dynamical model with Mike Anderson (CDWR). CDWR is currently working to implement the model on CDWR compute resources to test the model within CDWR. Through this process, we expect to identify potential transition challenges.
- The project team has published five peer-reviewed papers documenting the methodologies used within the different components of the project.

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Project: Advancing Water Supply Forecasts in the Colorado River Basin for Improved Decision Making

Principal investigator: Gerald Day, Riverside Technologies

Project year: 2

Year-end ARL: 2

Description: The project team is working with the CBRFC Community Hydrologic Prediction System (CHPS) operational forecast framework to deploy a distributed modeling environment that will accept gridded precipitation estimates (e.g., GPM) and facilitate the assimilation of a variety of sensors including SNOTEL point data, as well as MODIS-based snow products. The project will implement the NWS distributed Hydrologic Model (HL-RDHM), which utilizes the Snow-17 and Sac-SMA models as a first step for transitioning to operational distributed modeling at the CBRFC. Distributed snow modeling will provide more accurate representation of the spatial distribution of the snowmelt process and should lead to improved forecasts even before advanced data assimilation is introduced. In parallel, the Utah Energy Balance (UEB) model will be implemented in pilot watersheds to address the difficulties and assess the potential value of incorporating an energy balance snow model in an operational environment. CHPS will provide a flexible environment that will support the management of gridded forcing and measurement datasets, allow the use of multiple models in parts of the basin, and facilitate the incorporation of future advancements. In addition, CHPS will provide a framework that will enable the research team to assess the performance of different components of the forecasting process, i.e., forcing datasets, models, and data assimilation procedures. CBRFC has provided a letter of support for the project, recognizing this provides a low-risk approach to transition to an environment that will support improved process modeling and the incorporation of advanced observations.

End users: Colorado Basin River Forecasting Center, Denver Water, Dolores Water Conservancy District

Data sources, models, technology: NASA MODIS, GPM

Major accomplishments in CY 2016:

- Completed multi-year continuous simulation of coupled UEB + Sac-SMA models and computation of statistical error metrics of simulated runoff compared to observed stream flow at USGS gages. Distributed melt + rain outputs from UEB are used as input in Sac-SMA with lumped parameters.
- Continued work on evaluating the coupled UEB + Sac-SMA model and distributed Snow-17 + Sac-SMA model in RDHM framework in progress (Initial comparisons on Animas watershed complete, awaiting Sac-SMA parameters for other watersheds)

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Project: Cyanobacteria Assessment Network (CyAN)

Principal investigator: Blake Schaeffer, Environmental Protection Agency

Project year: 1

Year-end ARL: N/A

Description: The Cyanobacteria Assessment Network is a multi-agency project among the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, and U.S. Geological Survey to develop an early warning indicator system for algal bloom detection in U.S. freshwater systems. This research will utilize historical and current satellite data and supports federal, state, and local partners in their monitoring efforts to assess water quality to protect aquatic and human health.

The CyAN project will:

- Develop a uniform and systematic approach for identifying cyanobacteria blooms using ocean satellites across the contiguous United States;
- Create a strategy for evaluation and refinement of algorithms across satellite platforms;
- Develop an information dissemination system for expedient public health advisory postings;
- Understand connections between health, economic and environmental conditions to cyanobacterial and phytoplankton blooms;
- Disseminate satellite data through an Android mobile application and EnviroAtlas (www.epa.gov/enviroatlas).

End users: USEPA Regions, USACE

Data sources, models, technology: Landsat, Sentinel-2 and Sentinel-3

Major accomplishments in CY 2016:

- Developed preliminary versions of NOAA cyanobacteria algorithms implemented into NASA standard processing software
- Focused on subset of states (Ohio, Florida, California, Vermont, New Hampshire, Massachusetts, Connecticut, Rhode Island)
- Evaluated 3-band reflectance model using Landsat to predict chlorophyll concentrations in lakes and ponds
- Begun validation of Landsat surface water temperature algorithms

Plans or expectations for 2017:

- Evaluate linkages between in water constituents, such as disinfection by-products, with cyanobacteria concentrations
- Continued evaluation of various algorithms over increasing geographic extent (coverage become continental U.S.)

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B. Abbreviations & Acronyms

AGU: American Geophysical Union
ALEXI: Atmosphere-Land Exchange Inverse
AMIS: Agricultural Market Information System
AMSR-E: Advanced Microwave Scanning Radiometer - Earth Observing System
AOGEOSS: Asia-Oceania GEOSS
ARC: Ames Research Center
ARL: Application Readiness Level
ASCAT: Advanced SCATterometer
ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
CADRE: Crop Condition Data Retrieval and Evaluation
CBRFC: Colorado Basin River Forecast Center
CDWR: California Department of Water Resources
CFS: Climate Forecast System
CMORPH: Climate Prediction Center Morphing Model
CY: Calendar Year
DSS: Decision Support System
DSSAT: Decision Support System for Agrotechnology Transfer
ENVISAT: Environmental Satellite
EPA: U.S. Environmental Protection Agency
EROS: Earth Resources Observation and Science
ESA: European Space Agency
ESD: Earth Science Division
ESI: Evaporative Stress Index
ETM+: Enhanced Thematic Mapper Plus
FAS: Foreign Agricultural Service
FEWS NET: Famine Early Warning System Network
FLDAS: FEWS NET Land Data Assimilation System
G20: Group of 20
GDAS: Global Data Assimilation System
GEO: Group on Earth Observations
GEOGLAM: GEO Global Agricultural Monitoring
GEOGLOWS: GEO Global Water Sustainability

GEOS-5: Goddard Earth Observing System Model, version 5
GEOSS: Global Earth Observation System of Systems
GLDAS: Global Land Data Assimilation System
GOES: Geostationary Operational Environmental Satellite
GPM: Global Precipitation Measurement Mission
GRACE: Gravity Recovery and Climate Experiment
GRLM: Global Reservoir and Lake Monitor
GSFC: Goddard Space Flight Center
IPAD: International Production Assessment Division
JPL: Jet Propulsion Laboratory
LIS: Land Information System
LST: Land Surface Temperature
MERIS: MEdium Resolution Imaging Spectrometer
MERRA: Modern Era Reanalysis for Research and Applications
MODDRFS: MODIS Dust Radiative Forcing in Snow
MODIS: Moderate Resolution Imaging Spectroradiometer
MODSCAG: MODIS Snow Covered Area and Grain size
NASA: National Aeronautics and Space Administration
NASS: National Agricultural Statistics Service
NCRFC: North Central River Forecast Center
NDMC: National Drought Mitigation Center
NGO: Non-Governmental Organization
NLDAS: North American Land Data Assimilation System
NOAA: National Oceanic and Atmospheric Administration
NOHRSC: National Operational Hydrologic Remote Sensing Center
NRL: U.S. Naval Research Laboratory
OLI: Operational Land Imager
OSTM: Ocean Surface Topography Mission
PEER: Partnerships for Enhanced Engagement in Research
PI: Project Investigator
RZSM: Root zone soil moisture
Sac-SMA: Sacramento Soil Moisture Accounting
SIMS: Satellite Irrigation Management Support
SMAP: Soil Moisture Active Passive
SMOS: Soil Moisture and Ocean Salinity
SNODAS: Snow Data Assimilation System
SSM/I: Special Sensor Microwave Imager
SWAT: Soil and Water Assessment Tool
SWE: snow water equivalent
TM: Thematic Mapper
TMPA: TRMM Multi-satellite Precipitation Analysis
TOPEX: Topography Experiment
TRMM: Tropical Rainfall Measuring Mission

UN: United Nations
USACE: United States Army Corps of Engineers
USAID: United States Agency for International Development
USDA: United States Department of Agriculture
USGS: United States Geological Survey
VIC: Variable Infiltration Capacity
VIIRS: Visible Infrared Imaging Radiometer Suite
WAOB: World Agricultural Outlook Board
WSWC: Western States Water Council
WWAO: Western Water Applications Office

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C. Contacts

Water Resources Applications Area

Program Manager
Bradley Doorn
bradley.doorn@nasa.gov

Program Associates
John Bolten
john.bolten@nasa.gov

Christine M. Lee
christine.m.lee@jpl.nasa.gov

Forrest Melton
forrest.s.melton@nasa.gov